A SEARCH FOR THE INTERMEDIATE SUBGROUP OF THE GAMMA-RAY BURSTS IN THE SWIFT DATASET

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Abstract. It has been observed nearly 400 gamma-ray bursts by the Swift satellite. We search for a third (intermediate) subgroup of the bursts by the standard χ^2 method and F-test. Supports for the existence of this subgroup are found.

Key words: gamma-rays: bursts

1. INTRODUCTION

According to our knowledge, gamma-ray bursts (GRBs) are the most powerful explosions the Universe has ever seen since the Big Bang. Many papers on the different sky distributions of the different GRB groups were published (e.g., Balázs et al. 1998, Balázs et al. 1999, Mészáros et al. 2000a, 2000b, Mészáros & Štoček 2003, Vavrek et al. 2008), on the different phenomena of the short and long GRBs (Balázs et al. 2003, 2004, Fox et al. 2005) or on the searching for a third (intermediate) GRB subgroup (Horváth 1998, 2002, Mukherjee et al. 1998, Horváth et al. 2004, 2006, Chattopadhyay et al. 2007, Horváth et al. 2008, Horváth 2009). With the Swift satellite (Gehrels 2005), since November 20, 2004, we have a tool, which can solve the gamma-ray burst puzzle. We examine a GRB sample of the Swift catalogue that covers the period November 2004 - February 2009 (the first/last event is GRB041227/GRB090205) and consists of the 388 GRBs with measured duration.

2. χ^2 FITTING OF THE GRB DURATIONS

The first evidence of the existence of three GRB subgroups was found by Horváth (1998) the by χ^2 fitting (Trumpler et al. 1953; Kendall et al. 1973) of the duration distribution of the BATSE GRBs.

In Figure 1 there is a distribution of $\log T_{90}$ durations of our data sample. We created eight histograms of bursts' durations with different binnings and fitted them by one Gaussian curve (1G), by the sum of two Gaussian curves (2G), and by the sum of three Gaussian curves (3G).
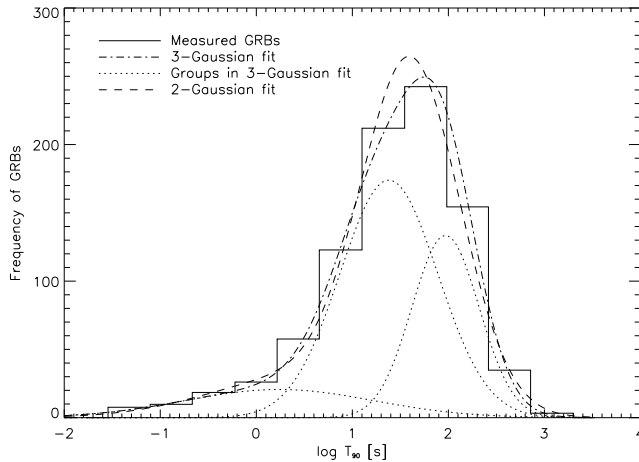
Fig. 1. Fitting of the $\log T_{90}$ histogram with 11 bins (fit No.VI.). The number of GRBs per bin is given by the product of the frequency and the bin width. The best fits with 2-Gaussian and 3-Gaussian curves are shown.

While fitting with three Gaussian curves, we obtained four fits out of eight, for which the decrease of χ^2, in comparison to two-Gaussian fit, is significant ($F \leq 5\%$). We consider the introduction of a third subgroup acceptable if the F-test gives the probability $\leq 5\%$ (Trumpler et al. 1953, Kendall et al. 1973, Band et al. 1997).

In all cases of the different binnings the one Gaussian curve do not fit the distribution because the goodness-of-fits are $\ll 0.01\%$. The fits with the sum of two Gaussian curves were in all cases statistically significant, because their F-tests were less than 5% (practically less than 0.01%) and the goodness-of-fits were always higher than 30%. The introducing of the third subgroup gave the F-test less than 10%, in some cases less than 5%. Average best fitted parameters are: for 2G: $\mu_1 = 0.33 \pm 0.13$, $\sigma_1 = 0.96 \pm 0.05$, $w = 0.17 \pm 0.02$, $\mu_2 = 1.62 \pm 0.01$, $\sigma_2 = 0.52 \pm 0.01$; and for 3G: $\mu_1 = 0.30 \pm 0.42$, $\sigma_1 = 0.87 \pm 0.28$, $w_1 = 0.17 \pm 0.05$, $\mu_2 = 1.12 \pm 0.13$, $\sigma_2 = 0.47 \pm 0.32$, $w_2 = 0.32 \pm 0.12$, $\mu_3 = 1.87 \pm 0.06$, $\sigma_3 = 0.36 \pm 0.04$.

3. DISCUSSION

To discuss the results, first of all, we should remark that we have proven the existence of the short and long subgroups in the Swift data-set by the χ^2 method. One Gaussian curve do not fit the duration. The fit with the sum of three Gaussian ones is acceptable. It is also highly remarkable that the weight of the short subgroup is in accordance with the expectation. As it follows from Horváth et al. (2006), in the BATSE Catalog the populations of the short, intermediate and long bursts are roughly in the ratio 20:10:70. Nevertheless, because the short bursts are harder and Swift is more sensitive to softer GRBs, one may expect that in the Swift database the population of short GRBs should be comparable or smaller than 20% due to instrumental reasons. The obtained weights (being between 10 and 26%) are in accordance with this expectation. Also the other values of the

Table 1. Results of the χ^2 fitting of the data sample with 388 GRBs.

Fit	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
No. of bins	25	15	31	20	30	11	21	51
1 G								
χ^2	97.48	56.59	94.46	69.00	97.51	65.63	85.11	125.34
μ	1.45	1.47	1.44	1.46	1.45	1.42	1.46	1.42
σ	0.93	0.83	0.89	0.87	0.90	0.86	0.88	0.90
2 G								
χ^2	17.03	7.49	23.11	10.86	27.47	3.81	18.94	42.00
μ_1	0.06	0.42	0.33	0.31	0.25	0.47	0.38	0.43
σ_1	1.09	0.92	0.97	0.94	0.95	0.94	0.95	0.95
μ_2	1.60	1.62	1.62	1.62	1.61	1.61	1.62	1.63
σ_2	0.54	0.53	0.52	0.53	0.52	0.51	0.52	0.51
w_2	0.85	0.83	0.82	0.84	0.84	0.82	0.83	0.79
F [%]	10^{-5}	10^{-2}	10^{-6}	10^{-4}	10^{-4}	10^{-2}	10^{-3}	10^{-8}
3 G								
χ^2	9.99	2.38	16.69	5.62	19.38	1.72	3.73	3.27
μ_1	-0.01	1.07	0.28	-0.28	-0.002	0.24	0.57	0.51
σ_1	1.13	0.32	0.98	0.61	0.83	0.98	1.09	1.01
w_1	0.15	0.23	0.17	0.09	0.13	0.13	0.20	0.22
μ_2	1.06	1.12	1.06	0.92	1.09	1.38	1.23	1.08
σ_2	0.35	1.24	0.31	0.33	0.34	0.51	0.38	0.32
w_2	0.29	0.30	0.24	0.22	0.31	0.57	0.39	0.23
μ_3	1.85	1.84	1.84	1.78	1.88	1.97	1.97	1.84
σ_3	0.37	0.33	0.38	0.43	0.36	0.35	0.31	0.38
F[%]	**2.52**	**3.63**	5.41	**4.21**	**4.94**	5.42	5.90	9.23

best fitted parameters - i.e. two means and two standard deviations - are roughly in the ranges that can be expected from the BATSE values. The differences can be given by the different instrumentations. For example, the mean values of the $\log T_{90}$ should be slightly longer in the Swift database compared with the BATSE data (Barthelmy et al. 2005, Band 2006). In Horváth (1998) the BATSE means are -0.35 (short) and 1.52 (long), respectively. Here we obtained for the sample: values from 0.06 to 0.95 (short) and from 1.60 to 1.63 (long), respectively. All this implies that - concerning the short and long GRBs - the situation is in essence very similar to the BATSE data-set.

Concerning the third (intermediate) subgroup, our results also supports its existence; from eight tests four ones gave significances below 5 %. Hence, strictly speaking, the third subclass does exist and the probability of the mistake for this claim is not higher than x %, where 2.52 < x < 9.23. This result is in accordance with the expectation, once a comparison with the BATSE database is provided. For the BATSE database the first evidence of third subgroup came from this χ^2 method, and hence also for the Swift database this test should give positive support for this subgroup, if the two data-sets are comparable. It is the key result of this article that this expectation is fulfilled. Our study has shown that the classical χ^2 fitting - in combination with F-test - may well work also in the Swift database (similarly to the BATSE database (Horváth 1998)). Horváth et al. (2008) confirmed the third subgroup in the Swift data set by the maximum likelihood (ML) method. Our significance between 2.52 % and 9.23 % is higher than the 0.46 % significance obtained by Horváth et al. (2008), which is expectable, because the ML method is a stronger statistical test. This is seen from two new studies, too: the ML test on the databases of RHESSI (Řípa et al. 2009) and

Table 2. Comparing of the methods and the results by the searching for the third (intermediate) subgroup of the GRBs. The used methods were: χ^2 method, maximum likelihood method on T_{90} (ML T_{90}), maximum likelihood method on T_{90} vs. hardness ratio (ML T_{90} vs. HR), and the others methods (not specified). As it is seen in this table, the third (intermediate) subgroup of the GRBs is supported by different methods in each data-set of every satellite (BATSE, Swift, RHESSI).

Methods	BATSE	Swift	RHESSI
χ^2	Yes (Horváth 1998)	Yes (Huja et al. 2009)	No (Řípa et al. 2009)
ML T_{90}	Yes (Horváth 2002)	Yes (Horváth et al. 2008)	Yes (Řípa et al. 2009)
ML T_{90}-HR	Yes (Horváth et al. 2006)	–	Yes (Řípa et al. 2009)
Other methods	Yes (Mukherjee et al. 1999, Chattopadhyay et al. 2007)	–	–

BeppoSAX (Horváth 2009) satellites, respectively, confirmed the existence of the third intermediate subclass; on the other hand, the χ^2 test either did not give a high enough significance for RHESSI data (Řípa et al. 2009) or was not used for BeppoSAX data at all (Horváth 2009). Comparation of the methods and the results is seen in Table 2.

4. CONCLUSION

Since the article Horváth (1998) described the existence of the third (intermediate) subgroup of GRBs in the BATSE database by the χ^2 fitting of the duration, we worked out an identical procedure on the existing Swift database. Similarly to the BATSE GRBs, the Swift GRBs do also require (but not as strongly as found by Horváth (1998)) an introduction of the third subgroup. Our results are very similar to Huja et al. (2009).

The results may be summarized in the following three points: 1. Concerning the short and long subgroups, our results are in accordance with the expectation: they are also detected in the Swift database and - in addition - in the Swift database the weight of the short subgroup is smaller, which can be well explained by the Swift's higher effective sensitivity to softer bursts. 2. The sample of 388 objects gives support (but not strong enough) for three subgroups, because from eight fittings of the whole sample four ones confirmed the existence of the intermediate subgroup on a smaller than 5 % significance level. Hence, concerning the Swift database, the situation is similar to the BATSE data set. 3. Similarly to the BATSE database, here it is shown again that the classical χ^2 test - in combination with F-test - is also effective for the Swift GRB sample.

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